Planning for Projects and Programs: Helping Decision Makers to Decide

Presentation to the Technology Strategy Team (TST) Meeting for Code Y

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Planning for Projects and Programs: Helping Decision Makers to Decide

- There are many problems of many types calling for decisions
- Many of these decisions are difficult to make because there is no obvious system of evaluation
- ➤ I will limit my discussion to making technology decisions in support of future missions
- I will do that by discussing 3 case studies
 - Mars program
 - NMP
 - Code R ECT
- My assertion is that this type of system has great value in making decisions and is worth considering in the Code Y program

Overview



- Answer question: "What is the best technology investment portfolio that enables a Mars exploration program that is resilient?"
- Approach: Integrate three different sources of important information:
 - Program science return
 - Based on a number of high priority measurements grouped into Pathways
 - One measure of resiliency is the ability to be responsive to multiple possible futures (pathways)
 weighted according to Program policy

Nine mission studies

- The missions studied a subset of the space of the various desired measurements
- The missions identified the enabling capabilities/technologies

Technology assessment

- Technology metrics,
- Current state,
- Performance forecast and funding requirements

Science Goals and Objectives

1	 Determine if Life Ever Arose on Mars Determine if Life Exists Today Assess the Extent of Prebiotic Chemical Evolution
2	 Determine the Evolution of the Surface and Interior of Mars ("Geology") Determine the nature and sequence of the various geological processes (volcanism, impact, sedimentation, alteration, etc.) that have created and modified the Martian crust and surface. Characterize the Structure, Composition, Dynamics and History of the Interior.
3	 Determine the Climate History for Mars Characterize the Present Climate and Climate Processes Characterize the Ancient Climate and Climate Processes
4	 Prepare for Human Evolution Acquire Martial Environmental Data Sets Conduct In-Situ Engineering Science Demonstrations Emplace Infrastructure for (Future) Missions

To Make the Strongest Program Plan

Wouldn't It Be Nice If We Had This Table?

Annual Technology Investment (\$M)	Preferred Technologies	Missions Enabled	MEPAG Measurements Enabled	<u>Comments</u>
25	а	3	XX XX	Insufficient dollars to complete all technologies for mission X, resulting in measurements Y not being done.
50	b c d e f	4 7 9	XX XX XX XX	Sensitivity of preferred tech #2 highly dependent on
75	a d e f g	3 4 7 9	XX XX XX XX	Reduction in 75M/yr budget by 20% would result in

Figures of Merit

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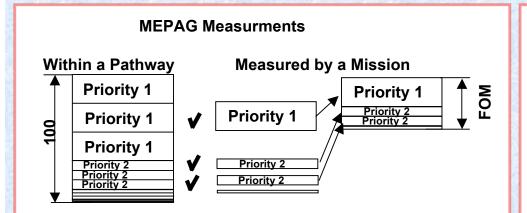


Figure of Merit for a Mission = within Pathway Number of Equivalent Priority 1
Measurements for Mission within a Pathway

Total Number of Equivalent Priority 1
Measurements within a Pathway

Figure of Merit for a Mission = within Pathway

All Measurements within Pathway

* (measurement completeness factor)

Measurements within Mission within Pathway

1

DF (measurement priority -1)

All Measurements within Pathway

* (measurement completeness) changes between 0 and 1

Figure of Merit for a Mission = Within Pathway mixture Pathway Weight

Figure of Merit for a Mission within Pathway

All Pathways

Relative Science Return for Mission

Mission	Baseline MSR/MSL 70-30	Lower MSR/MSL ratio 60-40	Lowest MSR/MSL ratio 25-75
MSL	29 *	39*	73*
VOL	14	14	14
POL	25	25	25
SAR	4	4	4
IMG	25	25	25
GMO	0	0	0
TEL	0	0	0
MSR	68 *	58 *	24*
WLD	25	25	25

^{*} Pro-rated values; e.g., 70-30 = 70% of 97 measurements = 68 for MSR and 30% for MSL= 29.

Mission Information

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Mission	Full Name	Earliest "Technology Possible" Launch Date	Mission Cost thru phase C/D; excl. technology development \$ M (real)
MSL	Mars Science Laboratory	10/2009	750
VOL	Mars Volcanology Rover	9/2009	600
POL	Mars Polar Layer Deposit Rover	10/2011	1000
SAR	Mars Advanced Orbiter SAR Mission	10/2009	490 ^b
Imaging	Mars Advanced Orbiter Imaging/Atmospheric Mission	11/2011	830 ^b
GMO ^a	G. Marconi Orbiter	7/2007	102
Telesata	Small Mars Telesat	7/2007	351
MSR_GB	Mars Sample Return Ground Breaking	2013	1400
Wildcat	Mars Wildcat	11/2011	890

Comments

a -Telesat orbiter will only be developed if G. Marconi Orbiter is not developed

b – Assumes one year of operations

Technology Path Network



	Precision Landing, kilometers	Impact Attenuation Landing Survivability, m	Hazard Avoidance, meters	On-orbit Science - Wavelength, meters	On-orbit Science – Resolution, meters/pixel	Forward planetary Protection – Measurement Time, hours	Forward Planetary Protection, No. org.	Surface Opts – Sample Char. TRL	Surface Ops – Sub Surface Access, meters	Surface Ops – Mobility, Meters/Sol	Surface Ops – Sample Handling, ppm	Back Planetary Protection, microns	Telecom, Mars Proximity, Megabits/sec	Telecom Mars to Earth, Megabits/ sec	Mars Orbit Rend. Capture time, Sols	Multimission survivability, Sols	Approach and Instrument Placement, Sols	Mars Ascent Vehicle, C
MSL	1*	2	3			6		8		10	11					16	17	
VOL	**	**	**			**	**	8		10a**			*			**		
POL	М	М	М			М		8a	9	10b	**		M*			М		
SAR				4									*	***,*				
Imaging					5								*	14***				
GMO ^b				*	*								13*	 a		16ª		
Telesat ^b				*	*								13*	 b		16ª		
MSR_GR°	М	М	М			М	7					12			15			18
Wildcat	М	М	М			М	7	8a	9a		11a MSL		М			М		

Comments

* = Dependant on MRO

** = Dependant on MER

*** = Dependant on industry or other government center

a = Does not include High Gain Antenna, listed as enhancing

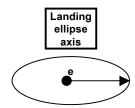
b = U.S. Telesat orbiter will only be developed if G. Marconi Orbiter is not developed

c = No technology development for Returned Sample Handling is represented here as that is being handled separately from the rest of the project. MSR has also expressed the need for some sort of orbiting attribute (preferably a Telesat) but since this attribute is not required to be one of the two Telesats listed here this requirement is not captured in this study.

M = The technology for that mission is dependent on MSL.

-- = Not applicable

1 - Data Sheet for Precision Landing



Attribute Definition: Semi-major axis of landing ellipse in kilometers

1. Estimate length of semi-major axis for this technology assuming task succeeds with probability 100%; (pick one)

obability 100 /6,	(pick one)		
Point estimate	Range estimate	е	P(x <e)< th=""></e)<>
(best guess)	(low to high)		0
0		or –	.25
	5 - 10		.50
			.50 .75 1.00
			1.00

2. Enter your estimate of actual probability of success that technology will be developed (0-100%).

95%

Estimate e

3. If the technology task fails, what is the best state-of-the-art likely to be achieved? (default—use current SOA)

100km

4. Estimate the budget profile in 3 year blocks (Real M\$)

5 0 0 0 '03-'05 '06-'08 '09-'11 '12-'15

5. Enter total technology development cost for this technology (2002 dollars)

Notes, Assumptions:

Assumes ability to land at up to 2.5 km above MOLA geoid (mean altitude) included

[Optional] This technology applies to following mission(s) (check all that apply if known, otherwise leave blank):

□VOL	□SAR	□MSR
□ROV	□IMA	□WLD
□RVL	□SSC	□SAB
□ MAG	□POL	□SCT₁

Baseline Results: MSR/MSL 70-30 (Sample Return) Science Path

Technol Investm (\$M/y	ent Technology	Missions Enabled	MEPAG Meas. Enabled, N	Comments	Tech. Candidates (Pathway Mix; Sensit. Analysis)
25 Technol Cost Profil \$M): [21, 21, 23, 3, 3, 3, 3, 3, 0, 0, 0, 0, 0, 0]	e (RY Imaging Orbiter On-orbit science resolution (wavelength) Telecom network, Mars to Earth	□ Volcanology Rover □ IMG orbiter Mission Cost = \$1430M	Max. Possible N= 39 E(N) = 30.2 Std. Dev. = ±10.9 ~16% of all possible measurements	Other single missions possible (e.g., MSR) with lower expected total science value due to higher technology development risk	Same result for 60-40 and 25-75 paths

Baseline Results: MSR/MSL 70-30 (Sample Return) Science Path

Technology Investment (\$M/yr)	Technology Candidates	Missions Enabled	MEPAG Meas. Enabled, N	Comments	Tech. Candidates (Pathway Mix; Sensit. Analysis)
50 Technology Cost Profile (RY \$M): [49.5, 49.5, 49.5, 20, 20, 20, 2, 2, 2, 0, 0, 0]	Mars Science Lab Precision landing Impact attenuation Hazard avoidance Forward planet. protect., time Sample characterization Mobility at 230-450m Sample handling, contam. Multimission survivability Approach/Instr. Placement Volcanology Rover Sample characterization Mobility at 160-200m Imaging Orbiter On-orbit science resolution Telecom network, Mars to Earth Mars Sample Return Precision landing Impact attenuation Forward planet. protect., time Forward planet. protect., # org. Back planet. protection Mars orbit rendezvous MAV Technology Cost = \$214M	□ M S L □ V O L □ I M G □ M S R Mission Cost = \$3580M	Max. Possible N= 136 E(N) = 43.2 Std. Dev. = ±27.3 ~23% of all possible measurements	POL enters at \$55M/yr Wildcat does not enter due to higher prob. of success for VOL technologies than Wildcat; Wildcat has same max. science value but uncertainty lowers its expected value.	Same result for MSR—MER path In Situ—MSL Path adds SAR and drops MSR because more uncertainties in MSR technologies reduces expected science value more than SAR would.

Explaining the Results—Sensitivity Analysis

- The determining factors for mission enablement (as the technology budget is increased from \$25M/yr to \$75M/yr) are:
 - Low technology budgets (\$25M/yr to \$35M/yr) limit possible missions because additional technologies exceed budget
 - As the technology budget increases, expected science value becomes the determinant of which missions enter solution; missions with high potential science, but numerous risky technologies can be displaced by missions with lower potential science and lower risk^a.
 - As the technology budget saturates near \$75M/yr (and all technologies/missions are enabled), the mission budget constraint limits number of missions to those with highest expected science value

^a Note: The term "low risk" defined as high probability of technology development success; "high risk" defined as low probability of success.

Baseline 70-30 Path: Missions Enabled vs. Technology Budget

MSR cost = \$1400M

Increasing Technology Budget——

\$25M/yr \$35M/yr \$45M/yr \$50M/yr \$55M/yr \$65M/yr \$75M/yr Mars Science Lab **Volcanology Rover Polar Layer Deposit Rover SAR Orbiter Imaging Orbiter Mars Sample Return** Wildcat



= in the optimal portfolio

CRW: Code Y Presentation 2/26/03

(+GMO

or TEL)

(+GMO or TEL)

25-75 Path: Missions Enabled vs. Technology Budget Sensitivity

MSR cost = \$1400**M**

Increasing Technology Budget ———

	\$25M/yr	\$35M/yr	\$45M/yr	\$50M/yr	\$55M/yr	\$65M/yr	\$75M/yr
Mars Science Lab			\triangle	\triangle	\triangle	\triangle	\triangle
Volcanology Rover	\triangle						
Polar Layer Deposit Rover			\triangle		\triangle	\triangle	\triangle
SAR Orbiter		\triangle		\triangle	\triangle	\triangle	
Imaging Orbiter	\triangle						
Mars Sample Return							
Wildcat						\triangle	

 \wedge

= in the optimal portfolio

(+GMO or TEL)

Baseline 70-30 Path: Technology Investment Portfolio vs. Technology Budget

MSR cost = \$1400M

Precision landing Impact attenuation Hazard avoidance On-orbit science wavelength On-orbit science resolution Forward planet, protect., time Forward planet. protect., # org. Sample characterization, 8 Sample characterization, 8a Sub-surface access, 2-3m Sub-surface access, 5-100m Mobility at 230-450m Mobility at 160-200m Mobility at 600-900m Sample handling, contam. 3-7k ppm Sample handling, contam. .5-1.5k ppm Back planet, protection **Telecom, Mars proximity** Telecom network, Mars to Earth Mars orbit rendezvous time Multimission survivability, 500 sols Multimission survivability,2500-4000 sols Approach/Instr. Placement

MAV

\$25M/yr	\$35M/yr	\$45M/yr	\$50M/yr	\$55M/yr	\$65M/yr	\$75M/yr
		•	•	•	•	
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Conclusions



- We have developed and demonstrated a method for allocation of technology investment which maximizes science return in a budget-constrained environment
 - Identifies missions that can be accomplished predicated on levels of technology investment
 - Observing the difference between maximum value of science measurements versus expected values shows that risk reduction strategies for technology developments should be a part of program planning.
 - The method synergistically includes Program goals, pathways, measurements, missions, capabilities, technologies, costs, etc.
 - Early results seem plausible and interesting!

Application and Extension of Methodology for NMP

Objectives

- Provide mission decomposition illustration with an example for formation flying
- Separate clearly the technology candidates from the capabilities they support
- Treat implicit technologies (i.e. those affecting design margins) as well as explicit technologies (i.e. those required directly to ascertain the science)

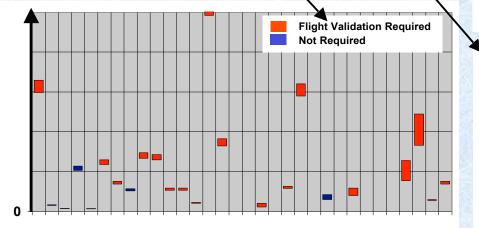
SUPPORTING DECISIONS

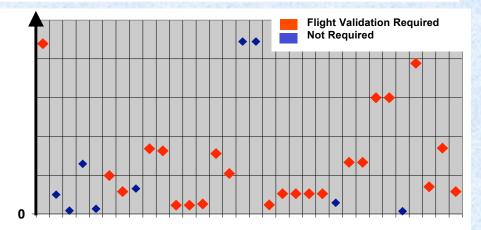


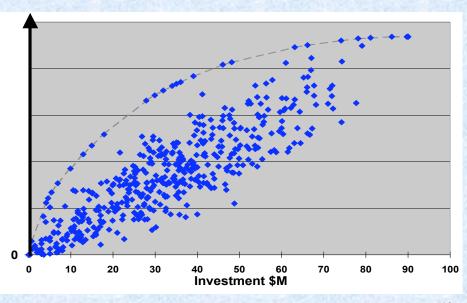
Ranking of Technology Capability Areas

Return on investment for Technology Portfolios

Return on investment for individual technologies







Conclusions

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- An auditable approach to ranking technology that permits traceability of the decision making process has been proposed.
 - One can more objectively isolate and resolve a point of disagreement on a system engineering level as opposed to arguing merits of dissimilar technologies.
 - Individual technology and technology portfolio costs are included in the ranking.
- The ranking approach includes technologies aimed at specific science measurements and spacecraft infrastructure (technologies in support of engineering goals)
- The ranking approach incorporated probabilities of technology development and mission success
- End-to-end example of auditable technology ranking procedures on a limited mission set has been demonstrated

Code R ECT Program: Pilot Case Study

- Develop and demonstrate analytical process to assess technology development and to guide ECT investment decisions
 - Assess & analyze technological progress
 - Collect performance data for ECT technologies
 - Measure & track technological gaps
 - Predict impact of investment on tech development
 - Estimate benefits to cost ratios
 - Optimize tech investment portfolios
- Conduct pilot case study illustrating systematic process for ECT tech investment and transition to Enterprises

ECT Case Study Technical Approach

- Select Pilot Mission Class (e.g. telescopes) that Leap-Frogs planned Enterprise missions and contributes to them
- Link Telescope Science & Technology Goals
- Identify Technologies and Performance Metrics
- Evaluate enabling impact of ECT technologies (10, 20, 30 years)
- Optimize ECT Technology Investment Portfolios
- Use lessons learned from pilot case study to derive process design for tech investment and transition to Enterprises

Conclusions

- I have shown an approach for improving decisionmaking.
- Three problem types have been illustrated
 - Assessment of technologies to maximize MARS program value
 - Evaluation of ROI on NMP technology investments
 - Assessment of technology investments for Code R
- This is only a sampling of types of problems amenable to analysis
 - Other examples/ suggestions?
- These problems are not exclusive to current 'customers'
- I offer our assistance in leading you all through analyses that pertain to decisions you wish to make.

BACKUP SLIDES



Decomposition of NASA Goal Values

- ➤ NASA establishes its goals and priorities based on mandates from Congress and the President. Relative Priorities of these goals establish Goal Values.
- ➤ Through decadal studies and roadmaps, Programs establish a list of Investigations required to accomplish NASA goals. The value of the NASA goal is apportioned to the values of investigations that enable it.
- Science workshops define experiments that partially accomplish investigation objectives. The planned value of these experiments is determined by:

Where:

Investigation Value is derived from NASA strategic plans that establish relative priority of the NASA goals.

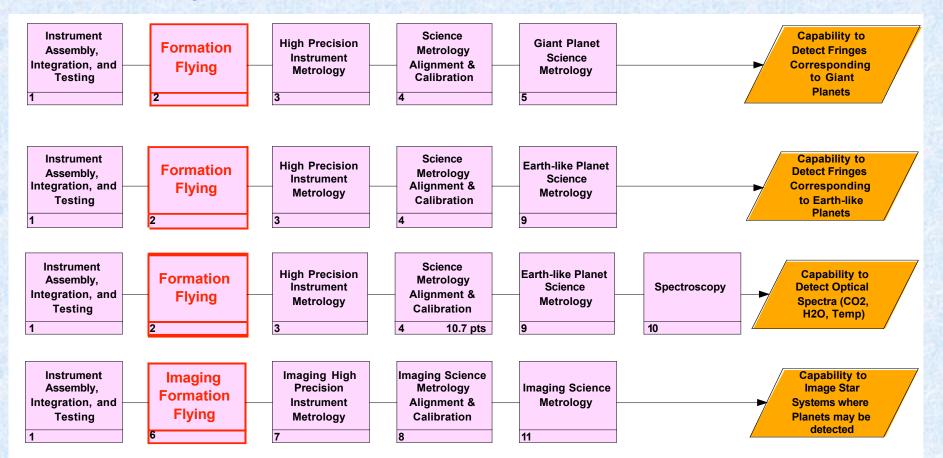
Completeness Factor describes the degree to which the given experiment achieves the investigation and is determined by scientists and programs.



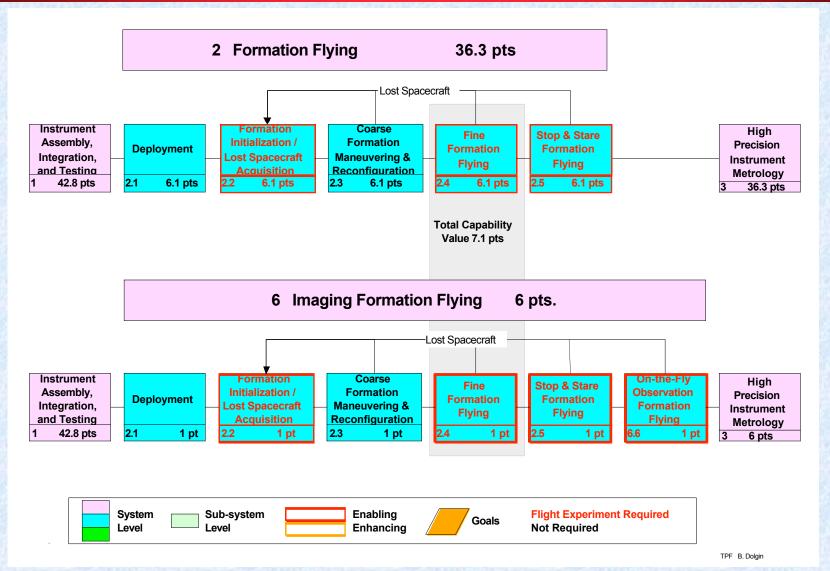
Mission Decomposition

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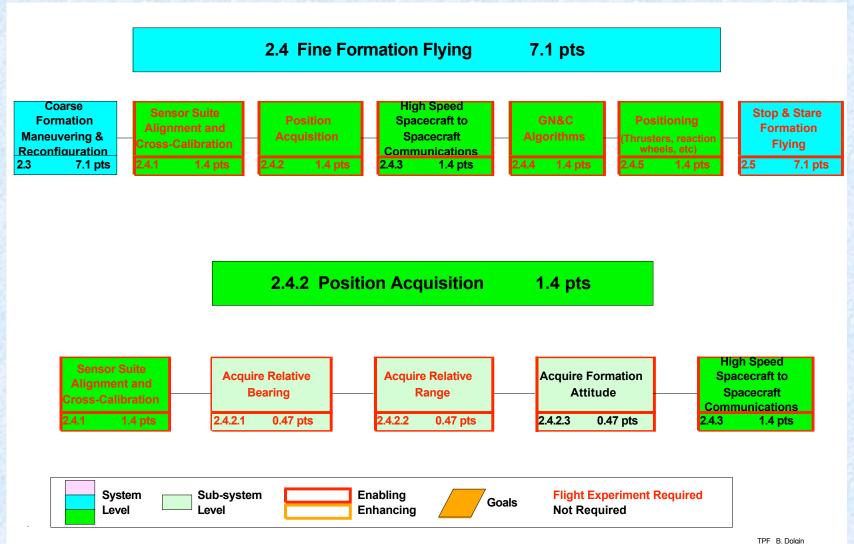
In order to eventually relate experiments (& their values, from equation (2)) down to the level of technologies, they must first be decomposed into a set of capabilities which enable them. Below is an example of the highest level of mission decomposition for TPF:



Illustrative Example: TPF Mission Decomposition



Illustrative Example: TPF Mission Decomposition





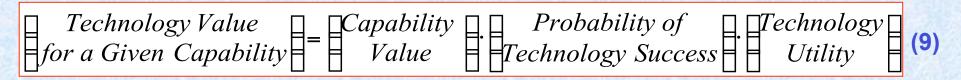
Technology Dependent Decomposition

- A mission is decomposed into the lowest level that it can be while still having mission capabilities (both science and engineering) that are independent of any technology that may be used to implement them.
- At this point, the lowest level mission capability must be further decomposed down to a level where a given technology <u>fully</u> satisfies the requirements of one or more sub-capabilities.
 - This process is called Technology Dependant Decomposition.
 - Technology Utility is the ratio of the value of the supported subcapabilities and the total capability value.
 - Science and Engineering Capabilities (& their values, from equations (7)
 & (8)) are decomposed in an identical manner at this level.
 - The values of sub-capabilities are calculated in the usual manner (equation (7))

Technology Value

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Once the capability value and technology utility are determined through decomposition:



Where: Probability of Technology Success is the likelihood that a technology, and all required supporting technologies, will be successfully developed and infused into the mission.

Finally, Technology Value may be computed as the sum of its contributions to all capabilities for all missions: